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Toward a new field of Development Engineering: Linking technology design to the demands of the poor

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Abstract

Engineering has the potential to accelerate the development of low-income communities by integrating insights from the social sciences along the entire arc of technological innovation, from idea to manufacture at scale. Here the case is made for a new field, Development Engineering, that will formalize this process by building on techniques from engineering, development economics, behavioral science, and sociology. Launching this discipline will require academic support infrastructures and sustained partnerships between academia, government, industry and the social sector.

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1. Introduction

Technological innovation is a central driver of social and economic development [1]; and with the expansion of research-focused institutions since the 1950s [2], scientists and engineers in academia and elsewhere have played an essential role in advancing human welfare.

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A profound example is the rapid diffusion of low-cost information and communication technologies (ICTs). In just one decade, mobile phone use has grown from one billion users to six billion in 2010 [3]. Although the broad welfare impacts of ICTs are difficult to quantify, several studies have convincingly documented specific benefits for those at the base of the economic pyramid. In India and Niger, for example, the availability of cellular coverage has improved farmers' access to markets, generating positive returns for both farmers and consumers [4], [5].

However, high-potential technology solutions—including those with economic promise (e.g. off-grid energy) and health benefits (e.g. low-cost water filters)—often fail to achieve sustainable benefits for the global poor. How can research institutions and universities more reliably generate and scale technologies with positive development impacts?

We believe that a concerted effort is needed to re-envision the design, evaluation, and scale-up of technologies that aim to improve the lives of the poor. Engineering innovation must be tightly coupled with the design of interventions that address persistent institutional gaps, market failures, cultural constraints, and behavioral biases—all of which prevent poor people from accessing and adopting technologies that could significantly improve their lives. This integrated approach will require accurate and timely data on consumer preferences and adoption patterns, as well as new tools and methods to measure the welfare impacts of new technologies in “real world” field settings.

Here we make the case for a new field, Development Engineering, which unites academics and practitioners in the integration of social science insights along the entire arc of technological innovation, from ideation to manufacture and distribution. To this end, a large consortium of collaborators has launched the Development Impact Lab [6], headquartered at the University of California (UC) Berkeley, with the goal of formalizing a new approach to humanitarian technology design.

To institutionalize this approach, it will be necessary to address the systemic barriers that have previously kept research institutions from engaging in this type of interdisciplinary creative work. These barriers include poor alignment of academic incentives with the practices required to reach real-world impact, and a need for ‘pull’ mechanisms that facilitate the translation of new technologies beyond academia. Novel funding arrangements, peer-reviewed publications, and platforms for partnership with industry and the social sector will be essential in this regard.

2. The Role of Missing Markets and Institutional Failures

One central challenge in Development Engineering is designers' limited understanding of the needs and preferences of technology users in low-income countries. In part, this is because people living in poverty are often priced out of the market for new products or services [7]. They find it difficult to secure credit for products with large up-front costs; and they lack information about the benefits of novel technologies [8], which makes it risky to invest [9]. Technology purchase and use are further limited by weak supply chains, missing infrastructure (e.g. electricity or roads) and uncertain property rights [10]. Because the poor are excluded from markets, they are left out of the iterative design process that markets can facilitate, through the generation of demand and price signals for different products. As a result, many technologies which are intended to be transformative—like the Computador Popular in Brazil and the Simputer in India [11]—fail to take users' needs into account, and do not achieve widespread adoption.

The situation is equally complex in the case of public sector investments. Innovations like educational tools and vaccines are often administered or subsidized by governments and non-governmental organizations (NGOs), because they generate public goods for which private individuals are unwilling or unable to pay. In such cases, engineers must design technologies with demonstrable social benefit, in order to justify public investment. In addition, they must design within the context of complex and often overwhelmed public institutions. This requires incorporating social and economic research throughout the innovation process.

3. Development Engineering: A Rigorous Approach to Technology Design

Development Engineering, as a practice and field of inquiry, is intended to accelerate the social benefits of technological innovation, by eliciting reliable information about user needs and incorporating this into design. The discipline builds upon techniques from engineering and the natural sciences, as well as economics, business, information science, design, and sociology. It also incorporates insights and practices from development

professionals in government, the private sector, and the social sector. The targeted outcome is a linkage of technological advances with social interventions needed to achieve lasting development impacts.

Within this emerging field, one area of focus is the creation of novel tools to characterize users' needs, particularly in the context of missing markets and institutional failures [12], [13]. In wealthy countries, product developers and marketing firms regularly monitor consumer demand using sophisticated data-intensive tools, including power and water utility meters, web and phone logs, computerized receipts, and marketing surveys. In addition, governments collect household- and individual-level data through voter activities, polls, and censuses.

Tools like these, if revamped to match the infrastructure and resources that are typically available in low-income countries [14], could be used to evaluate and iteratively design new pro-poor technologies. Over the last decade, there has been an explosion of adaptations that can be leveraged by Development Engineers, including willingness to pay experiments, contingent valuation studies, and distributed or remote measurement (using low-cost wireless sensors, mobile phone computing, and remote sensing). Importantly, these tools can allow for near real-time information on a technology's use, field performance, and social impact.

To lay the foundations for Development Engineering, we are drawing from a growing portfolio of case studies that involve both technological innovation and insights from social sciences. These include an electro-chemical arsenic remediation system for safe water currently being piloted in India [15]; a village-scale Base Transceiver Station for low-cost cellular communication, with deployments in Mexico and Indonesia [16]; and a cell phone-based digital microscope (CellScope) for disease diagnosis [17], being tested in countries throughout the world. These projects will use sensors, meters, or mobile phone technology to directly measure product adoption by individuals or communities, with user data fed back into the iterative design process.

Another example is the Rural Electricity and Power Project, which is developing an off-grid, solar electricity infrastructure ("microgrid") providing pay-as-you-go power to low-income communities in India [18]. The technology itself is a flexible mix of power generation, storage and distribution technologies, controlled through "smart" meters and scaled to meet the needs of rural villages. Initial design of the microgrid has relied on satellite data, household surveys, and other geo-coded information to determine population density, household income, and the location of grid infrastructure in the targeted region. These data have allowed the team to define initial system parameters. More generally, rich geocoded data can be used to optimize the choice of power source (e.g. solar, hydro, or wind) and to decide when it is most efficient to build independent microgrids— as opposed to extending national grids to remote rural households.

In this example, the research team's economists have designed pricing experiments into an initial deployment of microgrids in more than 40 villages, to generate a better understanding of rural households' ability to pay for electricity. The experiments randomize the electricity price offered to different households and villages, generating a demand curve for the local market. These data will directly inform the redesign of the infrastructure, including hardware and software configurations and the selection of more appropriate technologies for power generation, storage, and distribution. They will also inform the design of any social or economic interventions that must be co-implemented with the microgrid in future scale-ups.

The same team is creating new tools to measure individual households' electricity consumption at high temporal resolution, using non-invasive meters and mobile applications. The resulting high frequency data, which provide detailed information about electricity use patterns, can be used to generate consumer models, enabling the prediction of grid loads over time (and the anticipation of larger shifts in consumption over long time periods). In addition, the meters can eventually be used to provide households with real-time information about their own energy consumption, enabling them to make more informed choices about the use, costs, and benefits of electricity and appliances.

In combination, geodata and high-frequency user data, economic experiments, and household surveys will provide valuable information about the welfare impacts of gaining access to electricity. This information— which will be integrated into each iteration of the microgrid's redesign—will also be of interest to green tech investors, governments, and business.

The Rural Electricity and Power Project has relied on collaboration with a number of partners, including local energy sector firms, government agencies, and community organizations. This approach anchors the technology's design within existing institutions and contexts. For example, local businesses have experience with regional markets, supply-chains, and infrastructure. Government engagement is critical for understanding the impact of regulations and policies on microgrid design and pricing options. Community organizations can be essential for carrying out field-based economic experiments, which provide a voice for those impacted by new technologies.

Qualitative research and policy analysis, led by local academics, can be critical for understanding larger systemic barriers to uptake.

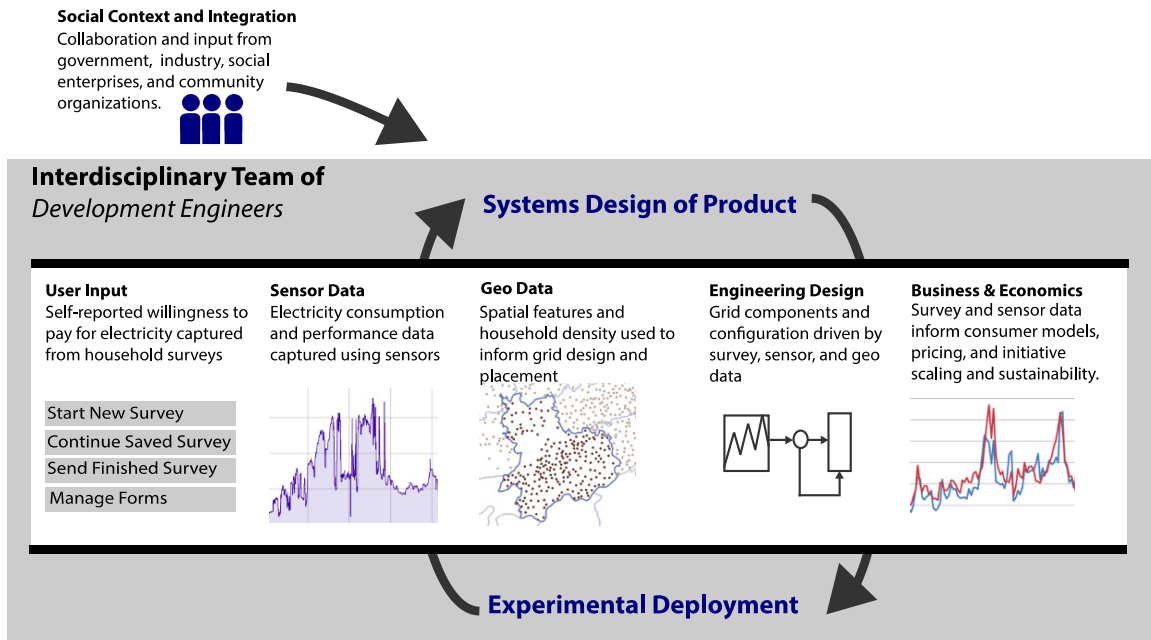


Fig. 1. Demonstration of the Development Engineering approach, using the Rural Electrification and Power Project as an example. The project is iteratively designing an off-grid power infrastructure for remote communities in India, drawing on information about household density and location, consumer demand for electricity, and other social, economic, and environmental factors. In this schematic, engineering design is integrated with social science and economics research, resulting in an iterative model of innovation. This process involves initial design of the intervention based on available data, followed by repeated and rapid experimental deployment and testing. Over time, both the technology and the business model are developed and better integrated with existing institutions and markets.

4. Early Efforts in Technology Design in International Development

The ideas and approaches associated with Development Engineering build on earlier efforts in technology for development. Since the 1970s, scientists and engineers have experimented with sustainable design, frugal engineering, and appropriate technology [19]. Many of these approaches emphasize cost reduction and simplicity as design principles. For example, International Development Enterprises (IDE) and the Program for Appropriate Technology in Health (PATH) have aimed to create high-impact, affordable technologies (like treadle pumps and single-use syringes) using market-based approaches for distribution. Other firms, such as IDEO.org and D-rev, have adapted user-centered design techniques for low-resource settings [20].

Academic researchers have also forged new paths. This has included initiatives like the Stanford University D-school, which has formalized the observation of work practice in low-income countries and applied the resulting insights to product innovation; the Humanitarian Engineering program at the Colorado School of Mines, which has developed a novel curriculum for community-based engineering design; and the MIT and UC Davis D-Labs, where inventors have engaged in co-creation of new products with local entrepreneurs, in an effort to identify opportunities for disruptive innovation [21].

With the discipline of Development Engineering, we propose two major changes in the design process. First, the community of innovators can be broadened by fostering interdisciplinary design teams that explicitly include social scientists alongside science and engineering researchers. This integrated approach will facilitate closer interaction with governments, the private sector, and civil society. It also will move technologists beyond the small-scale

surveys, focus groups, and observations that are typical in engineering deployments. These often capture the self-reported or observed preferences of elite individuals, and can be biased and non-reproducible [22]. They also fail to generate representative data on technology use or product performance at scale. Working together, social scientists and engineers can create more rigorous design and evaluation methods, like field experiments with representative samples and deployments that incorporate remote, sensor-based measurement of economic behavior.

Our second aim is to reconfigure the full arc of technology development; we redefine the approaches used in early-stage ideation and prototyping to incorporate not only user preferences, but also market barriers, business models, and institutional failures (which are typically addressed only at the later phases of design). In order to achieve scale these social challenges, along with environmental impacts and other community-wide issues, must be addressed from the beginning of the design process. We see this as an opportunity to incorporate best practices from earlier technology for development efforts, while engaging new disciplines to improve the process of innovation for development impact.

5. Creating and Supporting the Academic Discipline of Development Engineering

To build a critical mass of researchers, we are implementing a graduate-level curriculum in Development Engineering at UC Berkeley, in partnership with colleagues at MIT and other universities. The Berkeley program offers engineers and quantitative scientists a rigorous bench-to-community approach for designing development solutions. Students are taught to design, iterate, evaluate, and scale technologies alongside the social or market interventions required to achieve impact. For example, where the costs of a new product are extreme, financial products (like credit or uncollateralized loans) can be combined with the technology's rollout. Where wealth creation is a barrier, technological innovations can be introduced alongside job opportunities or vocational training.

In many ways, Development Engineering is simply the next step in a long tradition of solving societal challenges through science and technology. Since the early 1800s, which marked the formalization of civil and mechanical engineering, universities have repeatedly created and reinvented engineering disciplines in response to real world opportunities. Aerospace engineering emerged after the Wright brothers, electrical engineering after the invention of electrification, and biomedical engineering after the genetic revolution.

Learning from the emergence of another engineering field, biomedical engineering, we here propose five recommendations to launch this new academic discipline, with the ultimate aim of creating lasting, effective university engagement in science and technology for poverty alleviation.

- **New Engineering Tools and Approaches.** Over the last half-century, researchers created tools and methods—including innovations in optics, algorithm design, and chemistry—that enabled pursuit of dramatically new lines of inquiry in the field of biomedical engineering. For example, principles of fluid dynamics (derived from decades of research on fluid flow through pipes) are now applied to study arterial stent performance. Similarly, Development Engineering will build on generations of work in engineering, economics, and other core disciplines to expose and answer new questions about global development. It will also bring new techniques and technical tools and into practice, affecting social and economic development policy just as biomedical engineering has impacted the medical profession.
- **Mechanisms for Government Sponsorship.** As was the case with Bioengineering, which has been championed in the U.S. by the National Science Foundation and the National Institutes of Health, government support will be critical for the establishment of Development Engineering. As the federal agency responsible for civilian foreign assistance, the U.S. Agency for International Development (USAID) could play an effective role in supporting university programs in Development Engineering. Indeed, the UC Berkeley initiative in Development Engineering has recently gained support from USAID through its Higher Education Solutions Network, a consortium of universities working alongside the Agency to generate novel science and technology solutions for global development [23].
- **A Whitaker Foundation for Development Engineering.** Strong support from private research funders can accelerate the growth of new fields of research. In the U.S., the Whitaker Foundation contributed more than \$700 million over 30 years to promote bioengineering in higher education, providing fellowships and grants and

funding the creation of 75 biomedical engineering degree programs nationwide [24]. As a result of these efforts and concurrent federal support, there are over 17,000 bioengineers [25], and many more bioengineering graduates, designing health technologies in the U.S.

- **International and Multidisciplinary Collaboration.** Development Engineering is a discipline that straddles traditional university departments and professional schools. It also requires inputs from multi-national teams of researchers—not just students and faculty in the U.S. There is precedent for formalizing wide-spanning multidisciplinary collaboration. In the 1990s, the field of library sciences made a transition toward “information science,” resulting in the establishment of interdisciplinary Schools of Information with faculty expertise ranging from computer science and electrical engineering to ethnography, public policy, and economics [26]. To launch Development Engineering, quantitative science and engineering departments must foster similarly interdisciplinary research and training programs. At the same time, we must pioneer new models for productive international collaboration, including the application of distance teaching, remote team management, and cross-cultural learning. Innovators from wealthy countries must learn to build local research capacity while conducting research themselves [27]; for this, we may be able to learn from the biomedical research community or from engineering firms with global operations.
- **Career Trajectories and Performance Metrics.** To institutionalize Development Engineering, we must create academic rewards and incentives for researchers to tackle global development challenges, extending beyond the usual patents and publications. We must forge university infrastructure for the translation of development innovations. We must cultivate student engagement through courses, internships, and access to real world challenges. Finally, career trajectories for new graduates must be established, including academic hires and jobs in the public and private sectors. As globalization marches on, industry demand for engineers with experience in emerging economies will grow; this could create expanded career opportunities for students of Development Engineering.
- **Partnerships Beyond the Ivory Tower.** Since the ultimate goal of Development Engineering is to foster solutions for development, it will be important to create close collaborations with stakeholders outside the university, including those in NGOs, government, and the private sector. Novel activities and financing mechanisms are needed to both pull and push new ideas from the ivory tower to the “real world.” Development Engineers must go beyond the traditional academic practices and, in all stages, integrate connections to development practitioners. Most important of all, we must collaborate with the communities and individuals we work alongside, who have the unique ability to articulate critical needs and identify sustainable paths forward.

The new field of Development Engineering could catalyze whole streams of investigation, just as bioengineering has birthed fields like synthetic biology and regenerative medicine. Ultimately, it has the promise to transform the innovation ecosystem. Universities have both the opportunity and the obligation to better prepare the next generation of technologists, so that we can better address the challenges of poverty.

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